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EB-177F

PINGER

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PHASE I final report

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25X1

FINAL REPORT

for

PHASE I, PINGER PROGRAM

November 4, 1959

25X1

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LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

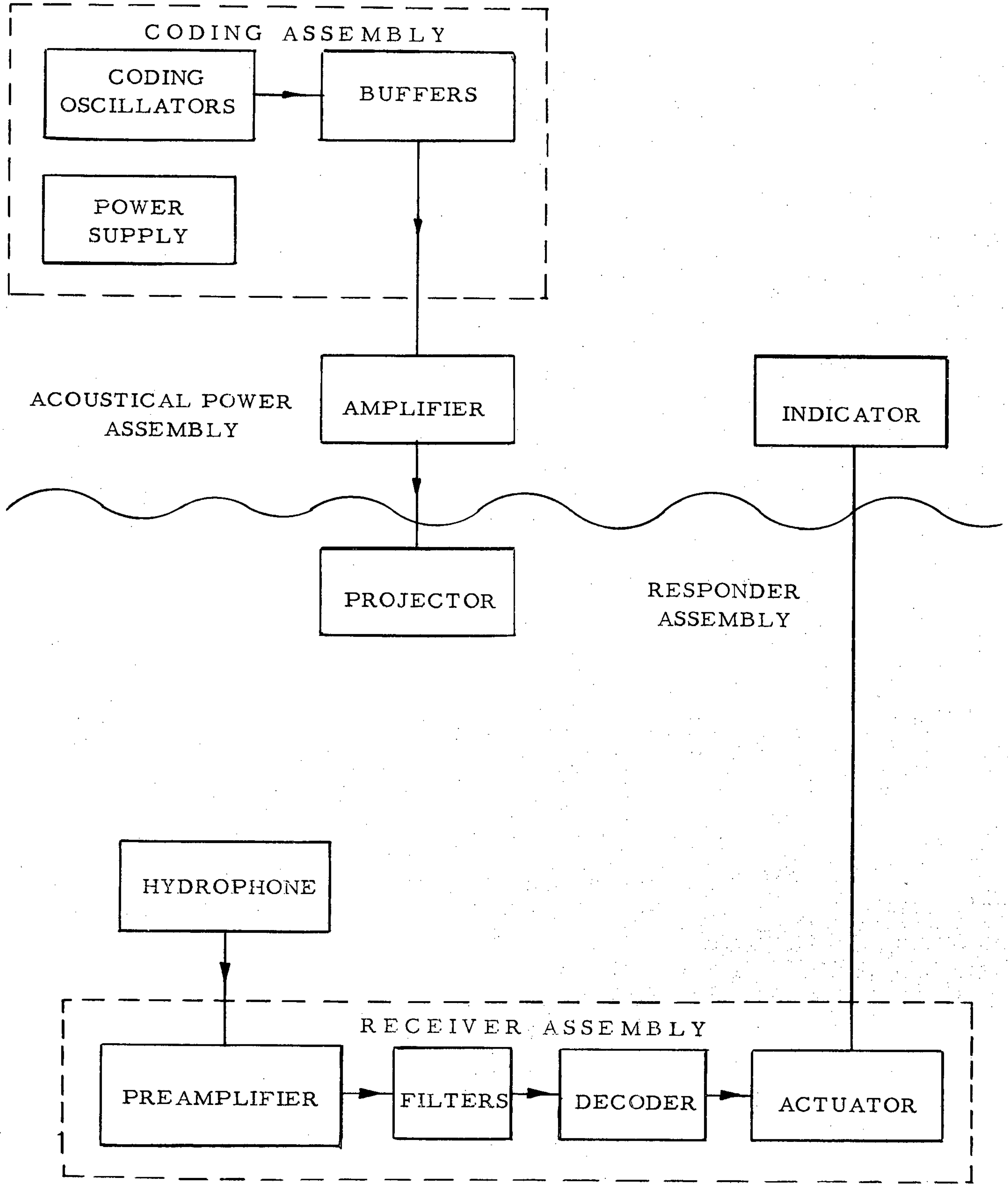
This final report summarizes the results of Phase I of a program with an ultimate goal of producing a lightweight, compact, secure, sonic locating system for use with underwater storage containers. This phase included the analyses and designs of the major electronic components. The final step was the demonstration of a preliminary engineering design. The design parameters require operation in sea or fresh water at depths of 30 feet, with response ranges up to one mile and response security from water noise and spurious signals.

The system, as presently developed, consists of - 1) a projector and coding assembly for the transmission of signals and 2) a hydrophone and receiver in the underwater container, with an indicator light on a float at the surface. The indicator unit takes the place in the system of the explosive squib which would activate the releasing mechanism. The receiver unit acknowledges receipt of a proper signal by causing the indicator light to be turned on.

Development and test of the system under Phase I has been completed. The test was conducted with one coding assembly and projector and two responder assemblies.

2.0 SYSTEM OUTLINE AND DESCRIPTION

A block diagram of the system is shown in Figure 1. The system design was directed primarily toward the development of a complete breadboard responder assembly with an indicator light. The acoustic power assembly was designed utilizing off-the-shelf material as much as possible.



PINGER BLOCK DIAGRAM
FIGURE 1

2.1 Acoustical Power Assembly

The acoustical power assembly was designed for operation aboard the [redacted] No special provisions are required for use in other vehicles. The assembly is small, durable and may be packaged compactly. The design includes as much off-the-shelf equipment as possible. 25X1

2.1.1 Coding Oscillators and Buffers

There are three coding oscillators with selectable frequency switching in the demonstration unit. The circuits appear in Figure 2. The oscillator assembly has a frequency tolerance of ± 25 cps over a normal temperature range.

The specific code used in this development phase has the following five frequencies: 18.9, 19.6, 21.0, 22.4, and 23.1 kc. Expansion to seven frequencies could be accomplished using 20.3 and 21.7 kc. While there are ten possible codes using three AND and two NOT frequencies, only five of these meet the security requirements and all others can be broken by a broadband notch covering the band of two adjacent frequencies.

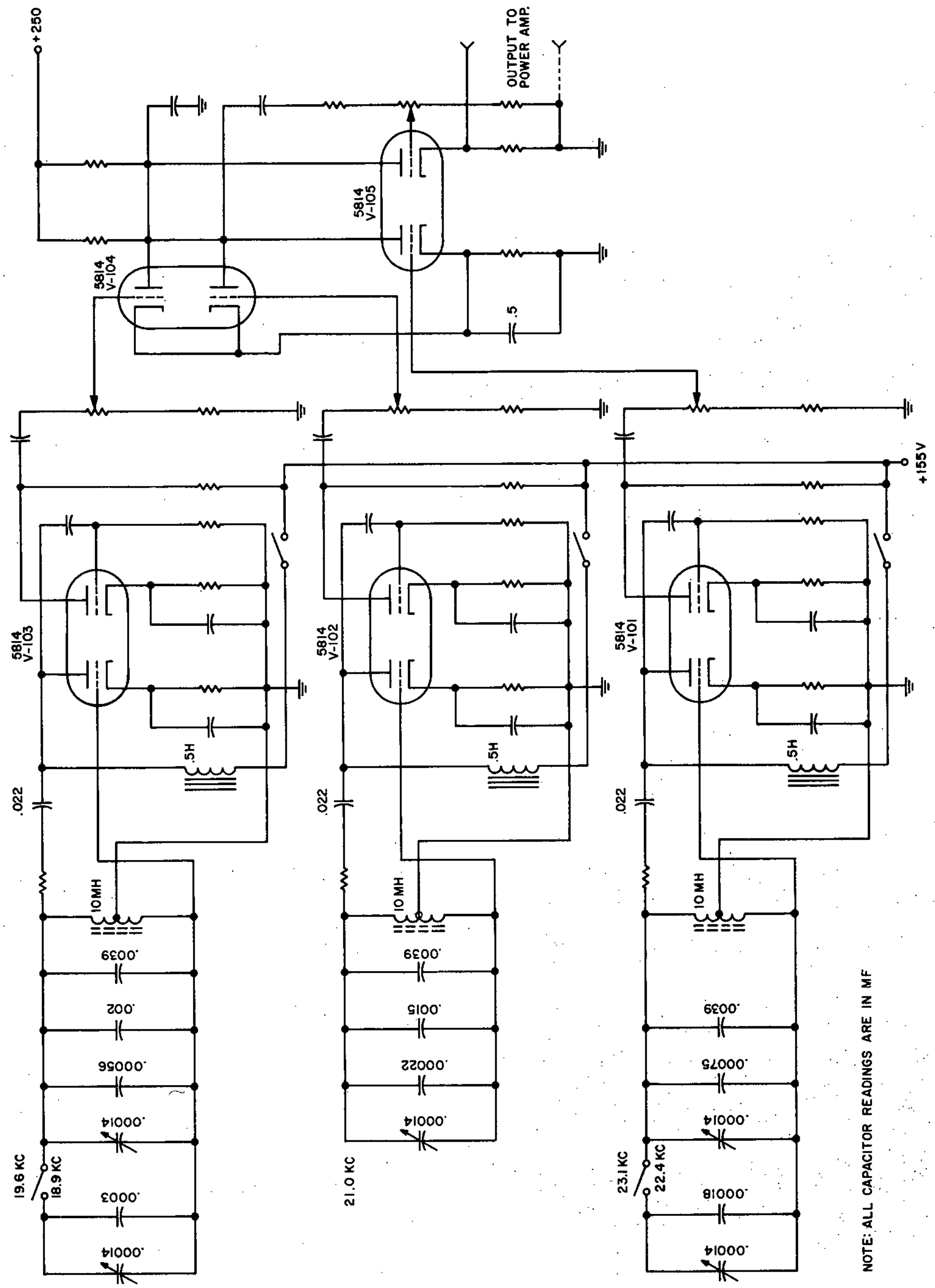
The outputs of the three coding oscillators pass through the buffers (Fig. 2) and are summed before passing to the amplifier.

2.1.2 Amplifier

A standard off-the-shelf 30-w MacIntosh amplifier was employed.

2.1.3 Projector

The projector of the demonstration design makes use of a standard off-the-shelf barium titanate cylinder. The dimensions are 3-1/8 in.



OSCILLATOR CIRCUITS

FIGURE 2

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outside diameter, and 2-1/4 in. height, with walls 1/8 in. thick. The housing is waterproofed by a neoprene boot and is oil filled. The oil loads the cylinder so the admittance of the transducer shows no motional loop for the breathing mode of vibration. A tuning coil is employed to cancel out reactance at the mid-frequency of the range of frequencies employed. The projector is down 8 db at 90° in the vertical plane at 21 kc.

2.1.4 Power Supply

The demonstration unit uses 115 volts, 60 cycle power, the source available on the [redacted]. The design of the unit would require 25X1 only minor changes to be adaptable to other sources, and does not preclude the possible use of portable power supplies.

2.2 Responder Assembly

The responder assembly consists of the components attached to, or closely associated with, the underwater storage container. The important units, as shown in the block diagram, Figure 1, are the preamplifier, filters, decoder and actuator (all directly attached to the container), the hydrophone, attached by a cable, and the indicator, attached by a cable of sufficient length to allow the indicator to reach the surface. All circuitry is transistorized. The battery group, not shown in the diagram, is also part of the assembly.

2.2.1 Hydrophone

The hydrophone of the responder assembly is constructed to float four feet above the container. It consists of an off-the-shelf barium titanate cylinder having 1-9/10 in. height, 1-1/2 in. outside diameter, and 1/8 in. wall thickness. The open circuit receiving sensitivity was about -103 db reference 1v/μbar. The hydrophone is virtually non-directional in both horizontal and vertical planes over the frequency range of interest.

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2.2.2 Preamplifier

The preamplifier (Figure 3) is a four-stage transistorized unit. The preamplifier response is shown in Figure (4). The gain of the preamplifier is 97 db. A triggering range of 40 db compressed by AGC converts the signal level to the magnitude required by the filters.

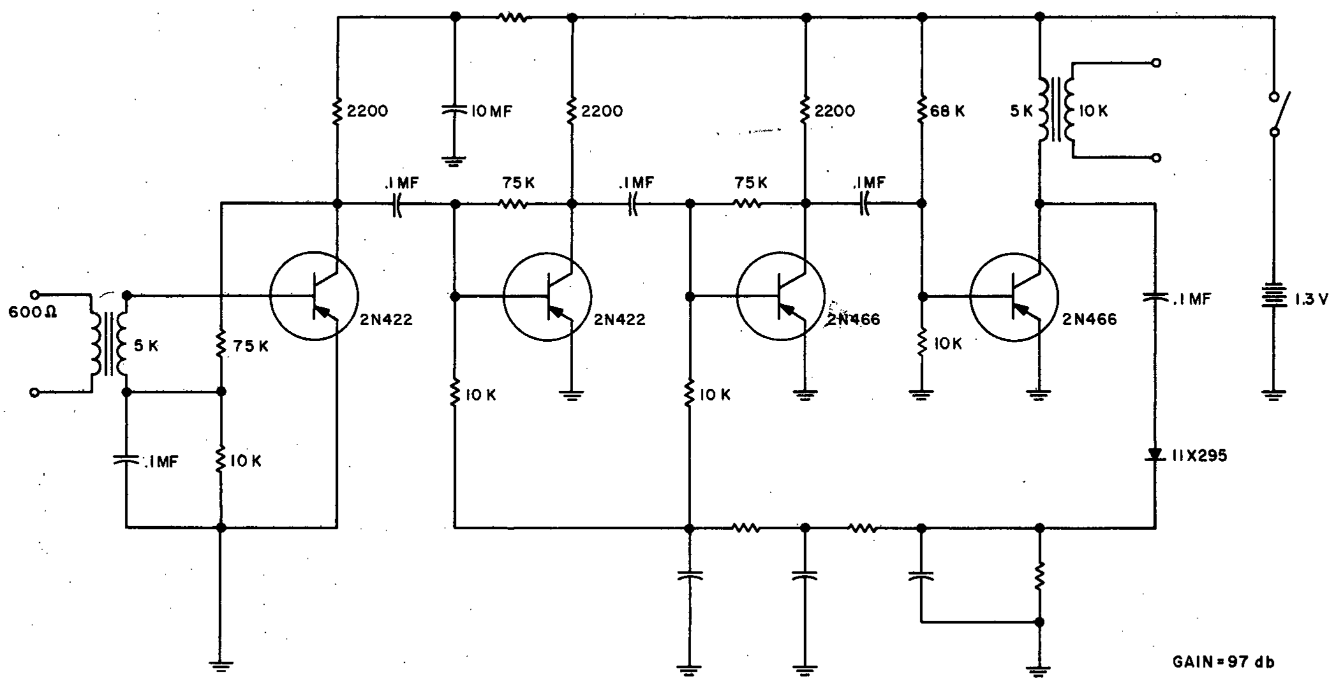
2.2.3 Actuator Electronic Package

A set of five filters, three of which have outputs when the proper code is received, separate the frequency components of the signal and feed them to the decoder. The decoder circuit is a five-channel unit with three AND and two NOT channels. When all of the decoder conditions are satisfied, the voltage level at the actuator input is raised to trigger the actuator circuit and close a relay. For the demonstration unit, a six-volt lamp above the surface of the water was used to indicate receipt of the proper code.

3.0 SYSTEM DEVELOPMENT

3.1 Acoustical Power Assembly

Since response to a single signal was not considered adequate to provide immunity against high level false signals or extraneous noises, a frequency selective code was used. As a minimum, it was required that the code be secure against a broadband signal with or without a single notch in the band and be sufficiently flexible to permit setting up one of twenty codes as a final design and one of three in a demonstration design. A five-bit code, two of which are NOT frequencies separated by one or two of the three AND frequencies, was selected as the best combination for both simplicity and reliability. By increasing the number of frequencies from five to seven, twenty to twenty-eight independent five-bit codes may be obtained.



PREAMPLIFIER

FIGURE 3

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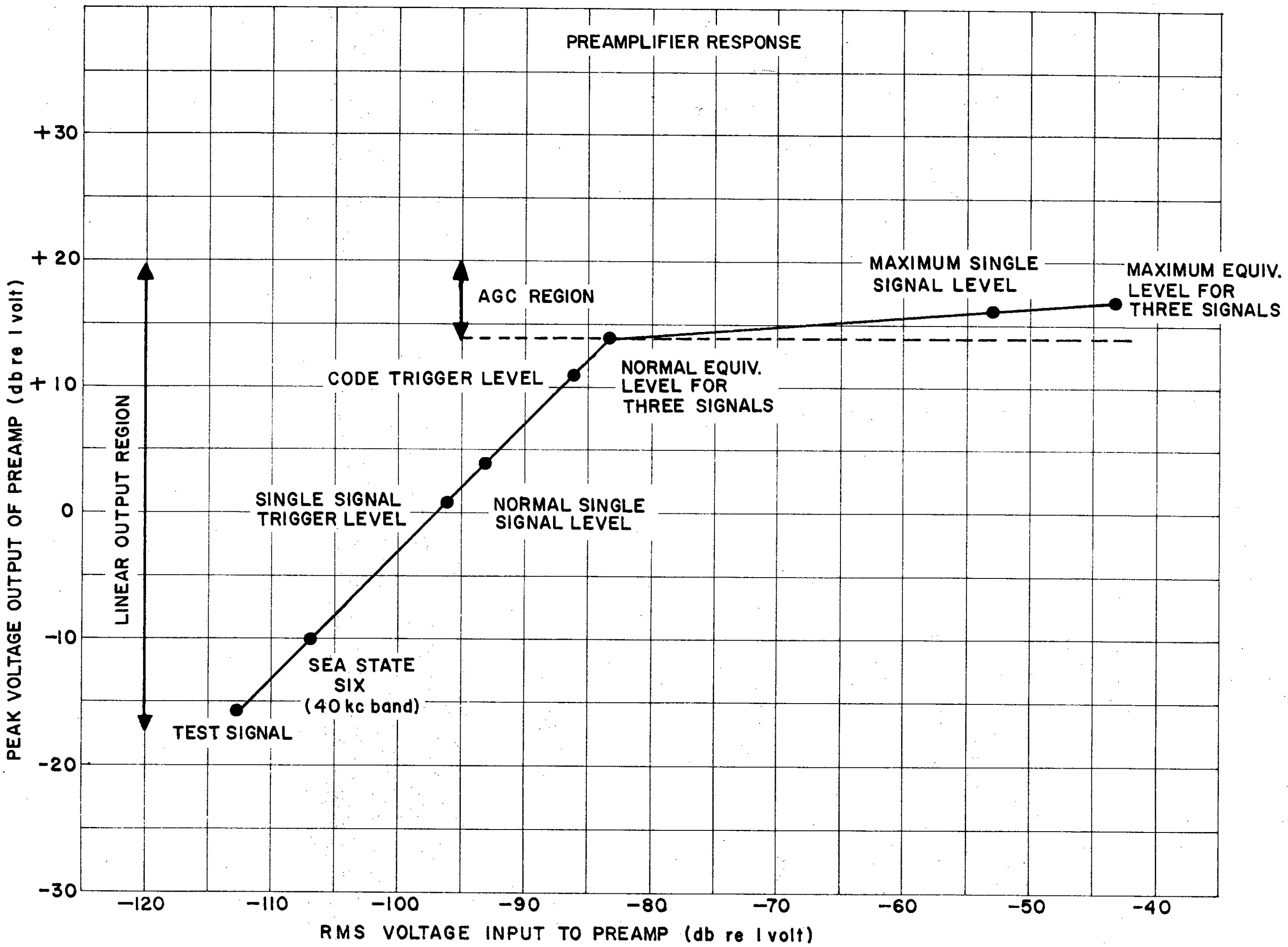
PREAMPLIFIER RESPONSE
PEAK VOLTAGE OUTPUT OF PREAMP (db re I volt)
RMS VOLTAGE INPUT TO PREAMP (db re I volt)
+30
+20
+10
0
-10
-20
-30
-120
-110
-100
-90
-80
-70
-60
-50
-40
LINEAR OUTPUT REGION
AGC REGION
MAXIMUM SINGLE SIGNAL LEVEL
MAXIMUM EQUIV. LEVEL FOR THREE SIGNALS
CODE TRIGGER LEVEL
NORMAL EQUIV. LEVEL FOR THREE SIGNALS
SINGLE SIGNAL TRIGGER LEVEL
NORMAL SINGLE SIGNAL LEVEL
SEA STATE SIX (40 kc band)
TEST SIGNAL

The result of the development was the selection of the following five frequencies: 18.9, 19.6, 21.0, 22.4, and 23.1 kc. The expansion to seven frequencies would be accomplished by the additional frequencies, 20.3 and 21.7 kc.

In order to assure an adequate signal well above sea noise and other noise sources at the responder hydrophone, the code trigger level was set 20 db above sea state six in a 40-kc band centered at 21.0 kc. In establishing the source level of the projector, consideration was given to spherical and cylindrical spreading losses and attenuation loss in shallow water.

The oscillator unit was held to a tolerance of ± 25 cycles over the temperature range which would normally be encountered. Tests of frequency stability were made over a considerably greater temperature range. The oscillator unit was refrigerated to a temperature 0° C; the oscillator frequencies were then measured from a cold start at this temperature. The temperature of the chassis was measured as the unit warmed up in a 27° C ambient condition. After stabilizing at 27° C, the unit was placed over a heating element and frequency measurements were made until the chassis temperature stabilized at 75° C. Frequency variations as a function of chassis temperature are shown in Table I . Line voltage variation and loading of the output of the unit have a negligible effect on frequency.

3.2 Responder Assembly

3.2.1 Responder Assembly Circuitry

The problem of low battery drain coupled with the necessity of relatively large amplification presented a problem in design. Although transistors are fairly well suited for this type of equipment, the "starved current" transistor type of circuit attempted in this preamplifier necessitated

TABLE I

Frequency Deviation with Chassis Temperature

	18.900 K.C.	19.600 K.C.	21.00 K.C.	22.400 K.C.	23.100 K.C.
0°C	- 5 cycles	- 6 cycles	- 19 cycles	- 14 cycles	- 17 cycles
10°C	- 4 "	- 5 "	- 17 "	- 13 "	- 16 "
15°C	- 3 "	- 3 "	- 14 "	- 9 "	- 14 "
20°C	- 1 "	0 "	- 10 "	- 7 "	- 11 "
25°C	0 "	+ 2 "	- 9 "	- 6 "	- 9 "
30°C	+ 1 "	+ 3 "	- 8 "	- 5 "	- 8 "
35°C	+ 1 "	+ 3 "	- 7 "	- 4 "	- 6 "
40°C	0 "	+ 2 "	- 6 "	- 3 "	- 4 "
45°C	0 "	+ 1	- 3 "	- 2 "	- 2 "
50°C	0 "	0 "	- 0 "	0 "	0 "
55°C	+ 3 "	- 3 "	+ 2 "	+ 1 "	- 1 "
60°C	+ 8 "	- 6 "	+ 4 "	+ 3 "	+ 4 "
65°C	+ 7	- 8	+ 7 "	+ 4 "	+ 5 "
70°C	+ 5	- 9	+ 6 "	+ 4 "	+ 5 "
75°C	+ 4	- 13	+ 5 "	+ 3 "	+ 4 "

making some basic measurements of transistors and their parameters which are normally not published. The idea that hearing aid circuitry would be applicable to the problem was considered. However, on closer investigation the power consumed by a hearing aid, although minute by normal standards, was in general three to five times too much for our application. Extremely low currents can change the parameters of a transistor considerably. These parameters, notably impedance changes, can of course be compensated for in design. More important, as collector current falls below one milliampere the available gain also begins to drop. Therefore, we had a choice between less current per stage and more stages or greater current per stage with less stages. As pointed out by Shea in "Transistor Audio Amplifiers," the actual transducer gain of a transistor falls off when the emitter current falls below one 1 ma. For a typical transistor the voltage gain at 1 ma would be 550. At 200 μa the voltage gain is 175. Whereas the gain of the preamplifier is changing considerably with current at these low levels, we also must be aware of temperature effects on gain in this low current preamplifier. We desired enough current flowing so that variations in temperature would not affect the gain of the preamplifier. Germanium units seemed to be the best choice for the preamplifier for the following reasons: availability, low cost, limited temperature range for the equipment, and high β. The fact that silicon transistors can work at lower current levels was completely offset by the very low β obtainable per unit and their high cost.

Preamplifier noise was not a problem. The noise contributed by the transducer on the input was not a problem either since the impedance was so low. Signal-to-noise ratio in any amplifier is determined by the first stage of the amplifier. The noise figure of a transistor comes from two sources, the emitter and the collector, and the total noise is a composite of these two. Collector noise is determined by the operating point of the

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transistor. Emitter noise, which is relatively constant, is determined by the physics of the transistor. The emitter noise is independent of collector voltage whereas the noise contributed by the collector increases with collector voltage. By selecting a transistor such as the Raytheon 2N422 and operating it with a collector voltage of about 1 v. and an emitter current of less than 1 ma (in this case about 200 μa) a minimum noise figure was obtained. In this preamplifier the noise level was well below the minimum signal level. The following stages of this preamplifier used the Raytheon Type 2N631 transistor in order to get maximum gain per stage with as little current as possible. The output stage (which does not appear in the preamplifier diagram, Figure 3, but is in addition thereto), is also comprised of two 2N631 transistors in push-pull class B.

During the design period of this present unit, two different designs for the preamplifier were tried - one used R-C coupling between the stages, the other was transformer coupled. The R-C coupled unit had the advantage of having slightly lower cost components but suffered in that less gain was obtainable per stage so that either more stages were necessary or maximum gain had to be obtained from the output stage. If more stages were used, more current was needed from our battery supply. If the Class B stage was to deliver maximum gain, a greater keep-alive forward current was necessary, also drawing more power from our source. Transformer coupling was used, therefore, in order to obtain the maximum gain per stage at minimum current levels and to minimize gain and current drain in the output stage.

The filters presented a problem only in that they had to be very sharply tuned yet physically small. The frequencies picked as AND-NOT frequencies worked well. A minor problem exists in that there is a possibility that the harmonics of two frequencies could beat together and result in the third frequency of a code that is being used. Example: If the code is 18.9, 21 and

23.1 the second harmonic of 21 kc is 42 kc. With a frequency of 18.9, the beat between 18.9 and 42 results in 23.1, the third acceptable frequency in our code. This would actuate the device even though only two frequencies are present. This problem could be partially corrected by spacing the frequencies geometrically instead of arithmetically. Filters placed at the amplifier input or output would be of little help here because these extraneous beat frequencies are generated within the preamplifier itself. This beating of frequencies and harmonic distortion takes place primarily because of the relatively small dynamic range of the receiver. This small dynamic range, however, is traced back to the small B-voltage used and the current-starved stages of the driver-amplifier and output. Here again we must balance current drain of the receiver against optimum desirable conditions. Sharpness of filter response must be maintained and care must be taken that the skirts of the filters are far enough down at the adjacent key frequencies so that a strong AND frequency will not actuate an adjacent NOT channel. When this happens although the correct AND frequencies are present to actuate the unit, the unwanted NOT signal will keep the code from operating the device.

3.2.2 Batteries

Battery source is the major consideration in designing the responder for an operating life of at least three years. A preliminary investigation was made of available data on a large number of types of primary cells applicable to design requiring current drain below one milliampere and actual current drain per cell of about 600 μa. Most of the information was obtained from the Power Sources Division of the United States Army Signal Engineering Laboratory. As a result, mercury batteries were selected for this phase of the development.

At the time, Mallory was the only manufacturer of mercury cells, although Burgess was expected to enter the field. Mercury cells are somewhat longer lived but have somewhat greater short-term voltage variations, and are more costly than the conventional Lechance cells. Shelf life measurements at 70°F showed nearly 100% capacity after three years. At 113°F capacity dropped to 75% after one year and to 50% after two years.

A requirement similar to ours has been investigated by the Power Sources Division for a 3-4 volt battery to operate at 0° to 60°C with +12% voltage regulation and to deliver one microwatt for one year. Their data on a group of ten Mallory RN-42 cells (flashlight battery type) operating initially at 1.4 volts and 1.6 milliamperes continuously for one year is given in Table II.

TABLE II

Mallory RN42 Cells at 1.6 Milliamperes Initial Current

Cell No.	Initial Open Circuit Voltage	Initial Closed Circuit Voltage	Closed Circuit Voltage after one year
1	1.422	1.421	1.037
2	1.441	1.439	1.032
3	1.432	1.431	.993
4	1.431	1.429	1.261
5	1.419	1.419	1.331
6	1.429	1.430	1.235
7	1.430	1.429	1.316
8	1.432	1.431	1.283
9	1.431	1.430	1.037
10	1.429	1.429	1.335

From the wide variation in cell voltages after one year, it may be inferred that this was close to the half-power life of the cells under the specified conditions. No information was available at the lower drain rates that we require. However, the above data gave us assurance that the expected cell life would be greater than one year.

More recent data on mercury cells and power supply circuitry adapted to long life application lead us to expect that the required three year life is feasible within the present state of the art.

4.0 TESTING

System tests were conducted in two phases: controlled tests in a tank, and an open water demonstration on the [redacted]. The former 25X1
tested the operation of the responder and decoding circuits, while the latter demonstrated the feasibility of the call-up system.

4.1 Controlled Tests

The security of the coding system was established in the tank test. For convenience in making adjustments and switching codes, the two responder assemblies were not packaged. Only the hydrophones were in the tank. With both responders set for the same code, a signal generator was set up to give all possible combinations of one, two, and three frequency outputs. Only the three proper frequency codes actuated the responders. Introduction of a fourth frequency, varied across the bank of operation, caused both responders to shut off when either of the NOT frequencies were transmitted. By switching one responder to a different code it was then proved that each responder would be actuated only by its proper code.

4.2 Open Water Demonstration

A test was conducted on board the on 25X1
September 15, 1959 in the presence of the customer's representatives.

Area - Hingham Bay
Sea State - 1
Depth of water - about 40 feet
Weather - overcast

The coding security tests were repeated at dockside.

Upon arrival in the selected area, the responder assemblies - designated A and B - were attached to two underwater containers and lowered to the bottom about 50 feet apart. They were marked with buoys for reference and recovery. The indicator lights for the responder assemblies were placed in a row boat. The test boat withdrew to 100 yards and the projector was lowered to a depth of about 8 feet. It was demonstrated that the indicator light of the unit being called would turn on only in answer to the assigned code. Tests were continued out to a range of .6 miles. At close range it was demonstrated that neither of the two units was actuated by a signal assigned to the other unit.

In order to determine the effect of noise on the responder the test boat kept its engine running throughout the test. Photographic records were made of the indicator lights, using a telephoto lens. Upon recovery - after about 1-1/2 hours in the water - the units were opened and inspected in the presence of the customer's representatives.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The completion of Phase I of the program shows that a system of secure codes with immunity to false signals and extraneous noise has been developed.

It was demonstrated that the call-up system has an effective operating range in excess of 1/2 mile. An appreciable number of the components are standard off-the-shelf items.

Several areas for further development remain. For a fully operational model, provision must be made for the projector to be operated from a simple coding generator, or from standard, commercially available oscillators. The responder assembly and associated equipment must be packaged. A release mechanism employing an explosive squib, and a float marker must be provided, as well as an arrangement for hydrophone release from the container. Provision must be made for setting the codes and installing the batteries just prior to use. The unit must withstand the shock of being dropped from aircraft and resist the effects of long submergence, corrosion, and fouling in either salt or fresh water. Design features which need further study include improvement of the filters, increasing the efficiency of the actuator unit, and utilization of the latest developments in long life batteries.

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